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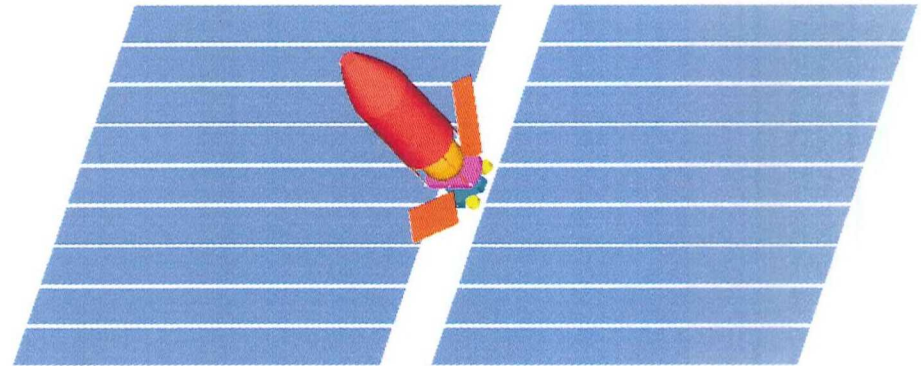
Direct-Drive Solar Electric Propulsion (SEP)

- When the output of a high-performance, high-voltage solar photovoltaic array (e.g., Stretched Lens Array) is directly connected to an electric thruster (e.g., Hall-effect thruster) with minimal power distribution system in between, a very fuel-efficient and cost-effective reusable SEP space tug becomes possible.
- As shown in the following two slides, such an SEP space tug could deliver 110 metric tons of cargo to the lunar surface at savings of more than \$3 billion compared to conventional chemical propulsion transport.
- The critical enabling technology for such SEP space tugs is the high-performance, high-voltage solar array, which must provide unprecedented performance metrics compared to today's state of the art arrays.
- The Stretched Lens Array (SLA) offers these required performance metrics, and ground tests and flight tests to validate SLA for SEP are critical to near-term availability of this important technology for space exploration.

600 kW SLASR-Powered SEP Tug Mission

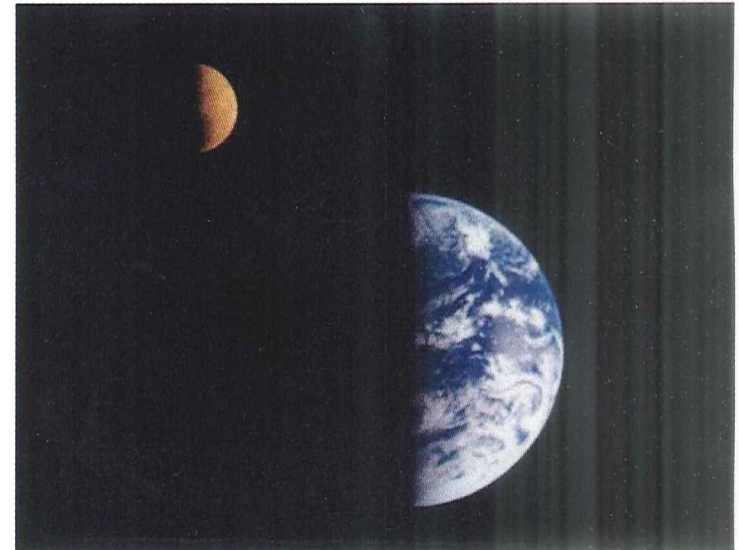
◆ SLASR-Powered SEP Tug

- Nominal 600 kW SLASR Array (Approx. 2,000 sq.m. Total)
- Hall-Effect Thrusters
- 600 Volt Direct Drive System
- 22 MT to Lunar Surface Each Trip
- 1 Year Max Round-Trip Time
- Reusable Tug (5 Round Trips)



◆ Reusable Lunar Tug Mission

- Five Round-Trips (One per Year) from LEO (400 km) to LLO, with On-Board Chemically Fueled Lander Delivering Cargo to Lunar Surface
- First LEO Launch Contains Tug, Xenon, Lander with Chemical Fuel, and Cargo
- Subsequent LEO Launches Provide New Xenon, Lander with Fuel, and Cargo, Which Dock with Tug in LEO for Next Trip
- 28 Degree Inclination Near Earth with Plane Changes Near Moon

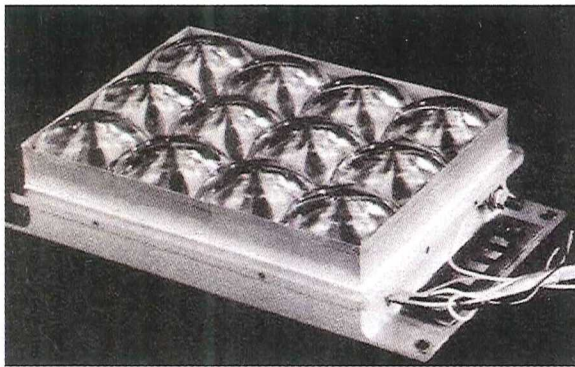


600 kW SLASR-Powered Lunar SEP Tug Offers Huge Savings

Conventional Chemical Cargo Transport		Reusable SLA-Powered SEP Cargo Transport	
Item	Mass	Item	Mass
LEO-to-LLO Vehicle (Expendable)	10 MT	LEO-to-LLO Vehicle (Reusable)	10 MT
Cargo	22 MT	Cargo	22 MT
LLO-to-Lunar Surface Fuel	15 MT	LLO-to-Lunar Surface Fuel	15 MT
LEO-to-LLO Fuel	80 MT	LEO-to-LLO Propellant (Xenon)	23 MT
Total Launch Mass	127 MT	Total Launch Mass (First Launch w/Vehicle)	70 MT
		Total Launch Mass (Subsequent Launches)	60 MT
Total LEO Launch Mass for Five Deliveries Over Five Years (110 MT Total Cargo)	635 MT	Total LEO Launch Mass for Five Deliveries Over Five Years (110 MT Total Cargo)	310 MT
Launch Costs Using Shuttle-Derived Heavy (\$10 M/MT from ATK: safesimplesoon.com)	\$ 6,350 Million	Launch Costs Using Shuttle-Derived Heavy (\$10 M/MT from ATK: safesimplesoon.com)	\$ 3,100 Million

- ◆ **SEP Offers Over \$3 Billion in Savings Just in Launch Costs per Tug**
- ◆ **SEP Offers Additional Savings of 4 Fewer LEO-to-LLO Transfer Vehicles**
- ◆ **More than 5 Round -Trips May Be Practical for SEP Tug (More Savings)**
- ◆ **For 70-MT-Class Shuttle-Derived Launch Vehicles, SEP Approach Will Require Half as Many Launches as Chemical Approach, and, as ATK Accurately States, “ Fewer Launches + Fewer Payloads + Fewer In - Space Assemblies = Higher Mission Reliability ”**

Background: Mini-Dome Lens Array on PASP-Plus and SCARLET Array on Deep Space 1



Mini-Dome Lens Array Flew on
PASP-Plus Flight Experiment in
1994-95 and Performed Very Well
in High-Radiation Elliptical Orbit

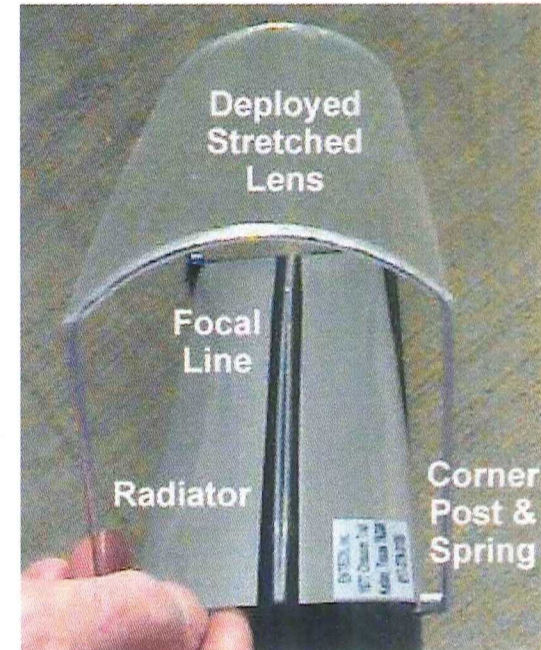


SCARLET Array Flew on Deep
Space 1 in 1998-2001 and
Performed Flawlessly for 38
Month Extended Mission

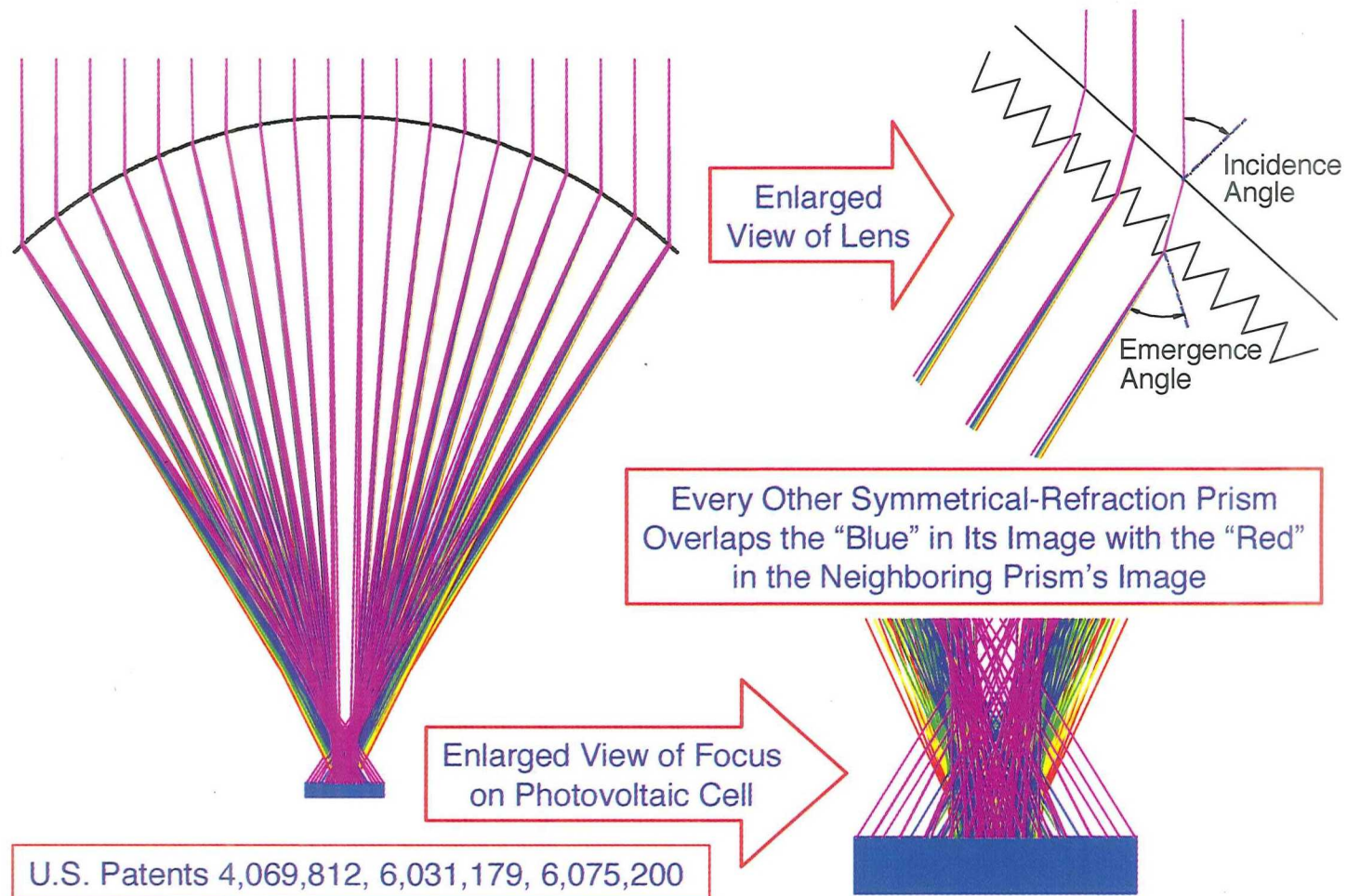
Stretched Lens Array (SLA) Approach



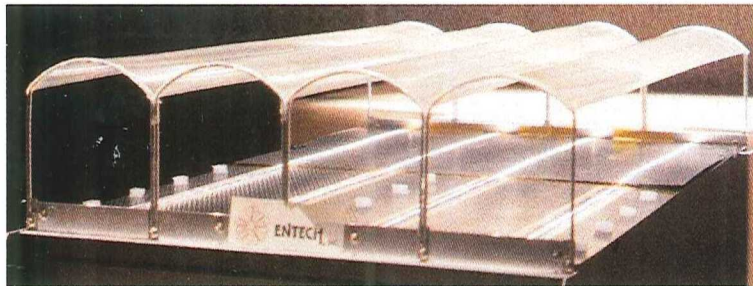
Flexible Silicone Lens Folds Flat Against Radiator Sheet (Containing Solar Cells) for Compact Launch, and Deploys on Orbit Using Lengthwise Tensioning to Support Arched Lens in Proper Position



Unique Lens Provides High Optical Performance, Color-Mixing, and Unparalleled Error Tolerance



Two Versions of Stretched Lens Array (SLA)

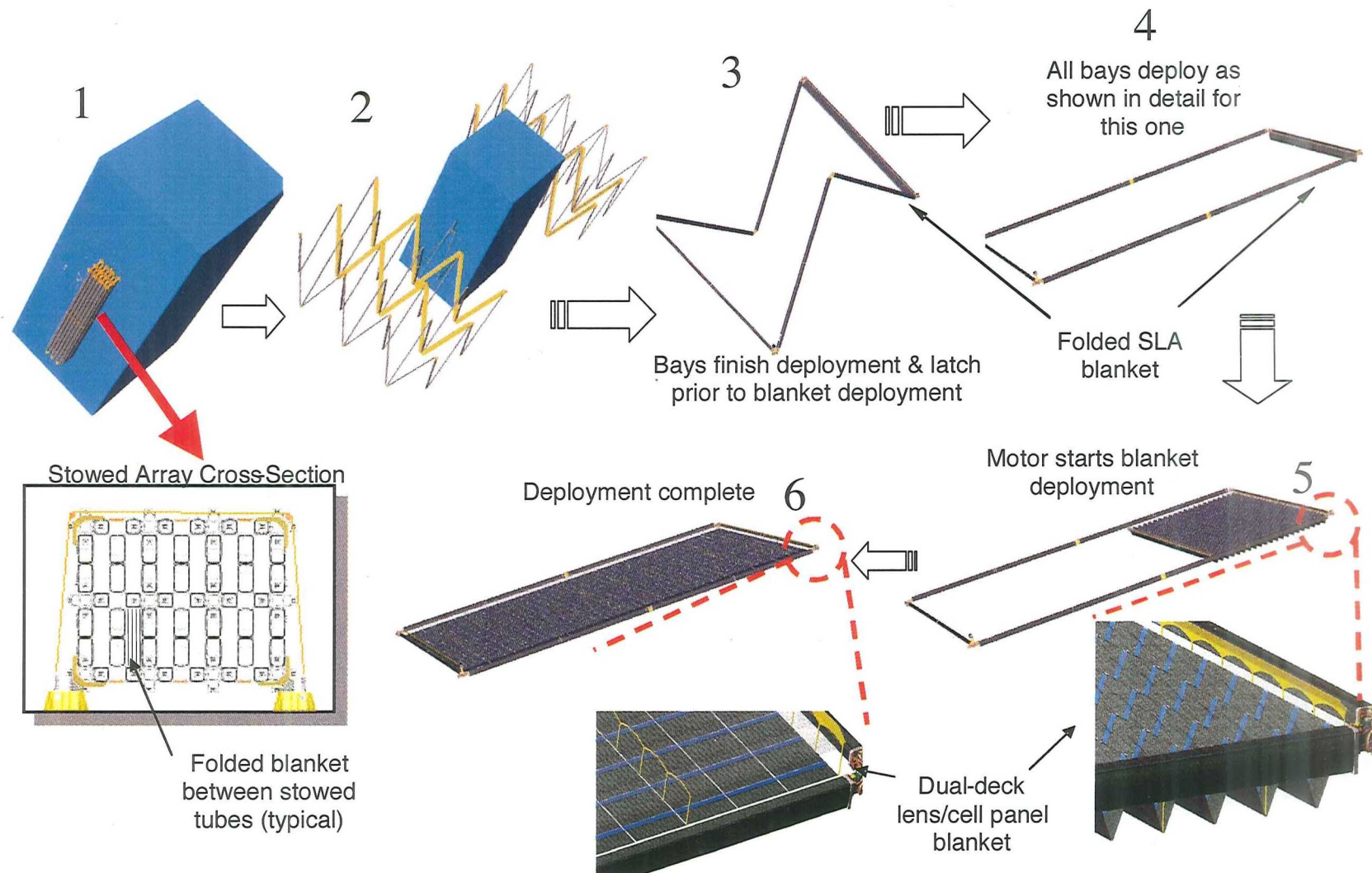


Flexible-Blanket Version (Above) of SLA Uses End Tensioning to Deploy and Support Lenses and Radiator Blankets



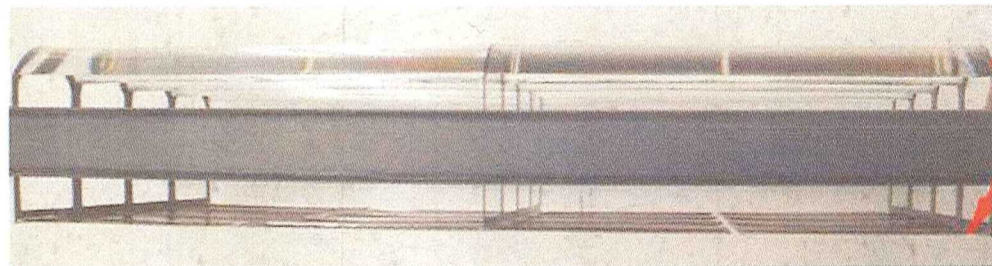
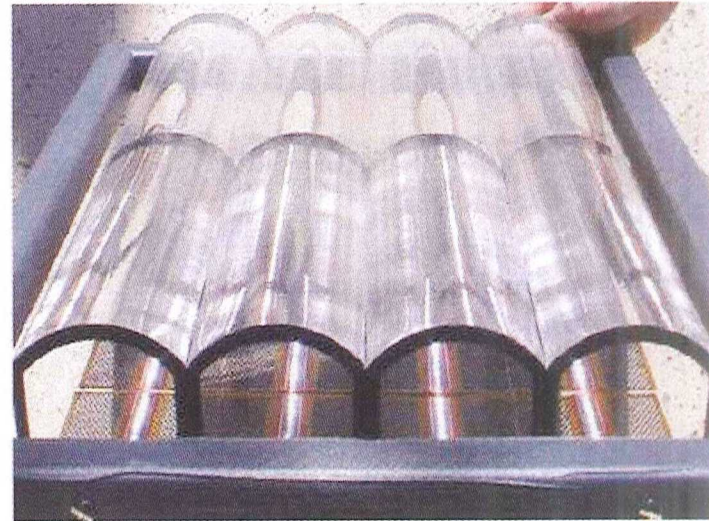
Rigid-Panel Version (Above) of SLA Uses Pop-Up Lenses on Lightweight Honeycomb Panels

Stretched Lens Array SquareRigger (SLASR)



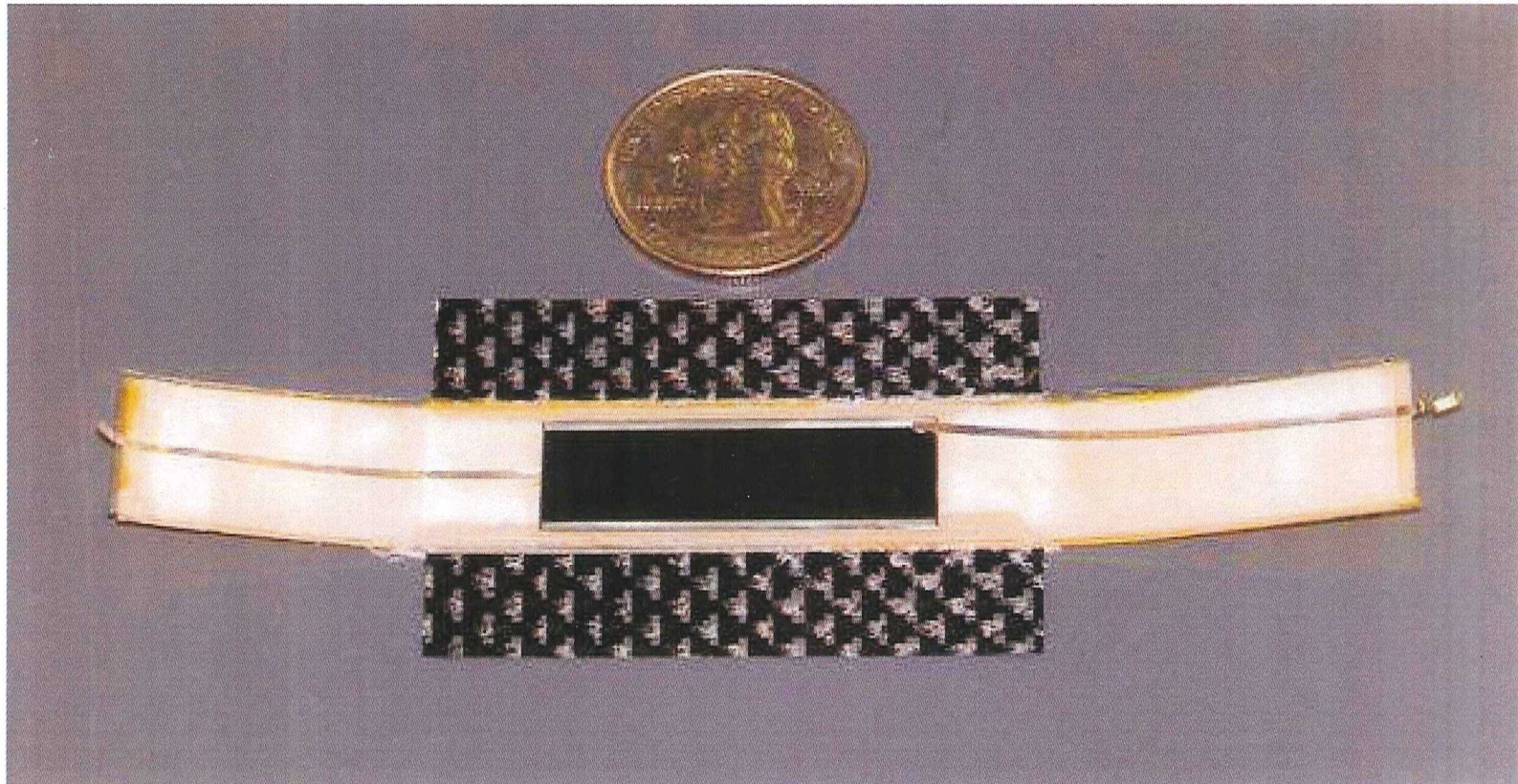
Prototype Stretched Lens Array SquareRigger (SLASR) Hardware

Prototype Hardware Shows
That the SLASR Approach
Provides Excellent Deployment,
Support, and Alignment of
Lenses and Radiators
Containing Solar Cell Receivers



Gossamer
Lens and
Cell
Blankets

Fully Encapsulated SLASR Receiver Sample



Relocation of 1 kW *SunLine* Array with 600-Volt Photovoltaic Receiver Circuits from Hawaii to ENTECH



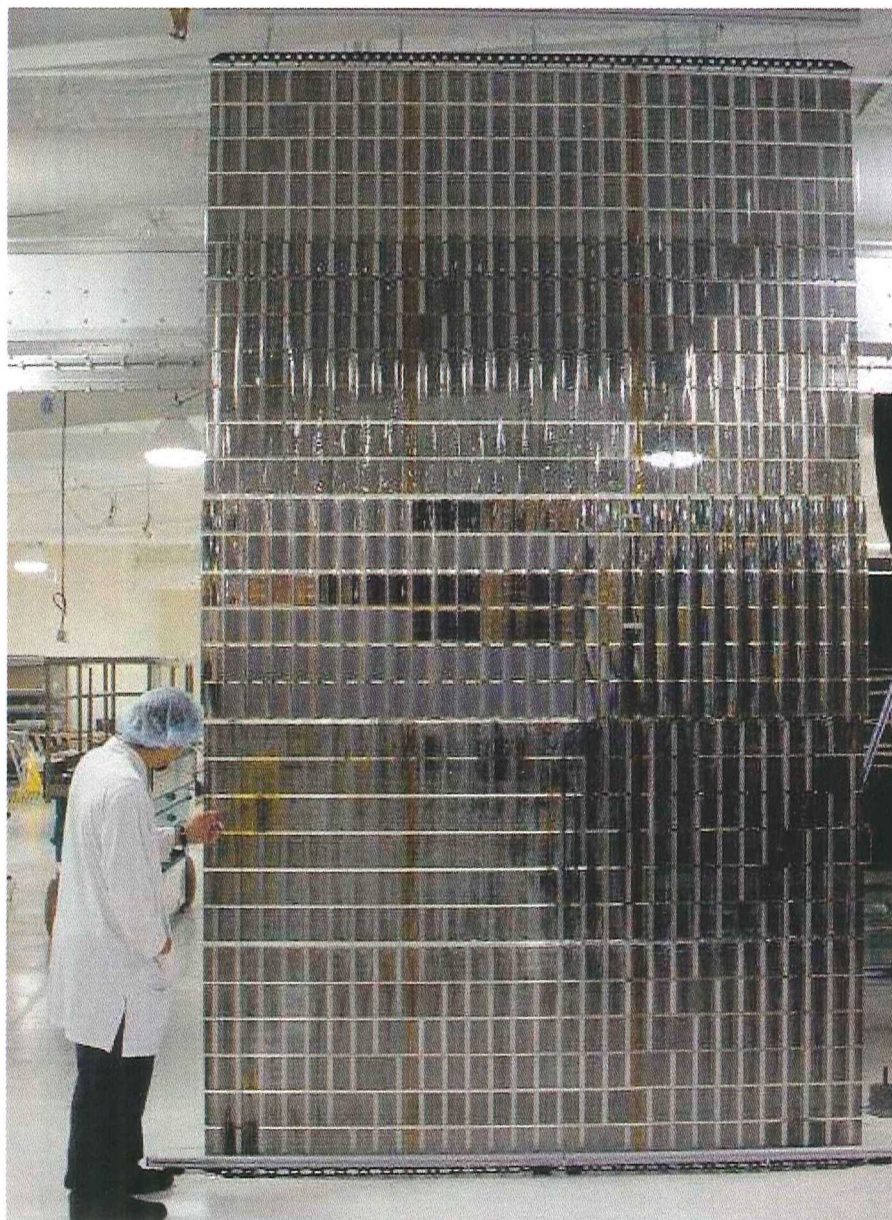
NASA SunLine at ENTECH July 25, 2005

Each 26X Concentrator Uses ENTECH Color-Mixing Lens

Over Boeing Triple-Junction Solar Cells

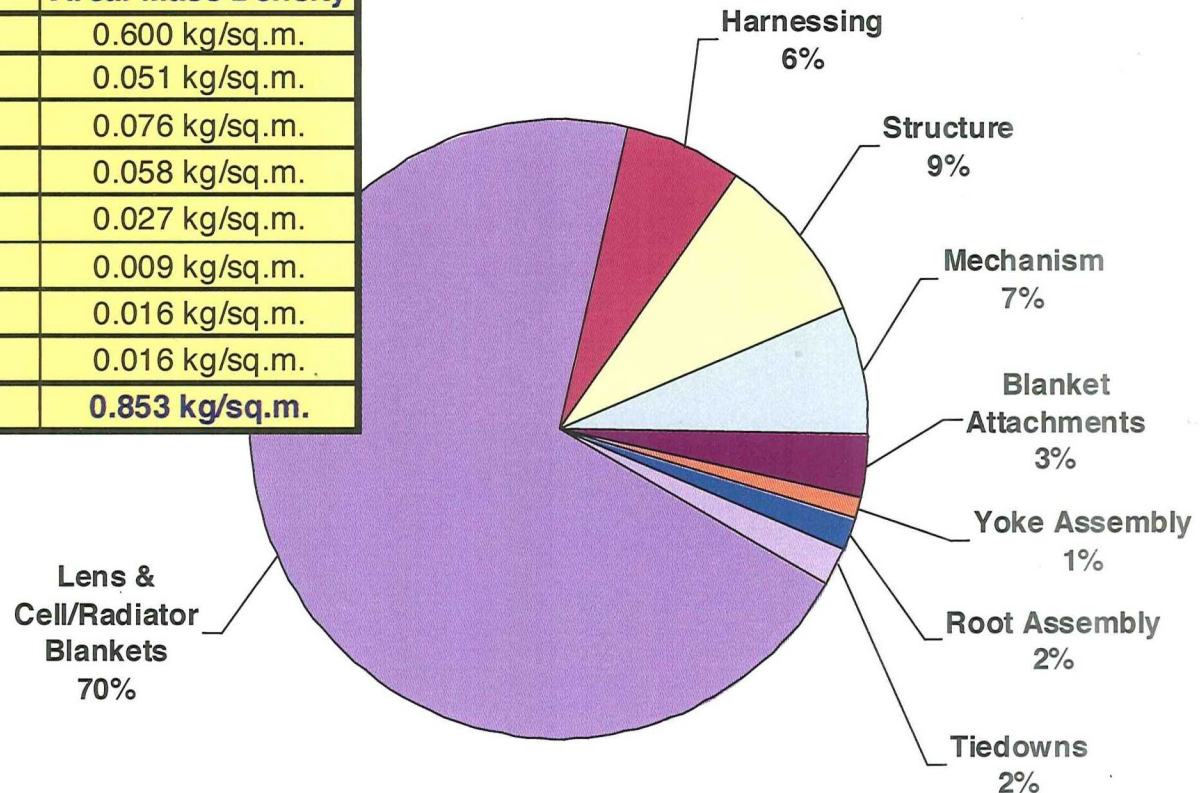
Full-Scale SLASR Bay.

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Mass Breakdown for 100 kW Stretched Lens Array SquareRigger (SLASR) for Current Technology and Normal GEO Radiation Shielding

Element	Areal Mass Density
Lens & Cell/Radiator Blankets	0.600 kg/sq.m.
Harnessing	0.051 kg/sq.m.
Structure	0.076 kg/sq.m.
Mechanism	0.058 kg/sq.m.
Blanket Attachments	0.027 kg/sq.m.
Yoke Assembly	0.009 kg/sq.m.
Root Assembly	0.016 kg/sq.m.
Tiedowns	0.016 kg/sq.m.
Total	0.853 kg/sq.m.



**Note that the Lens
& Cell/Radiator
Blankets Comprise
70% of Total Mass**

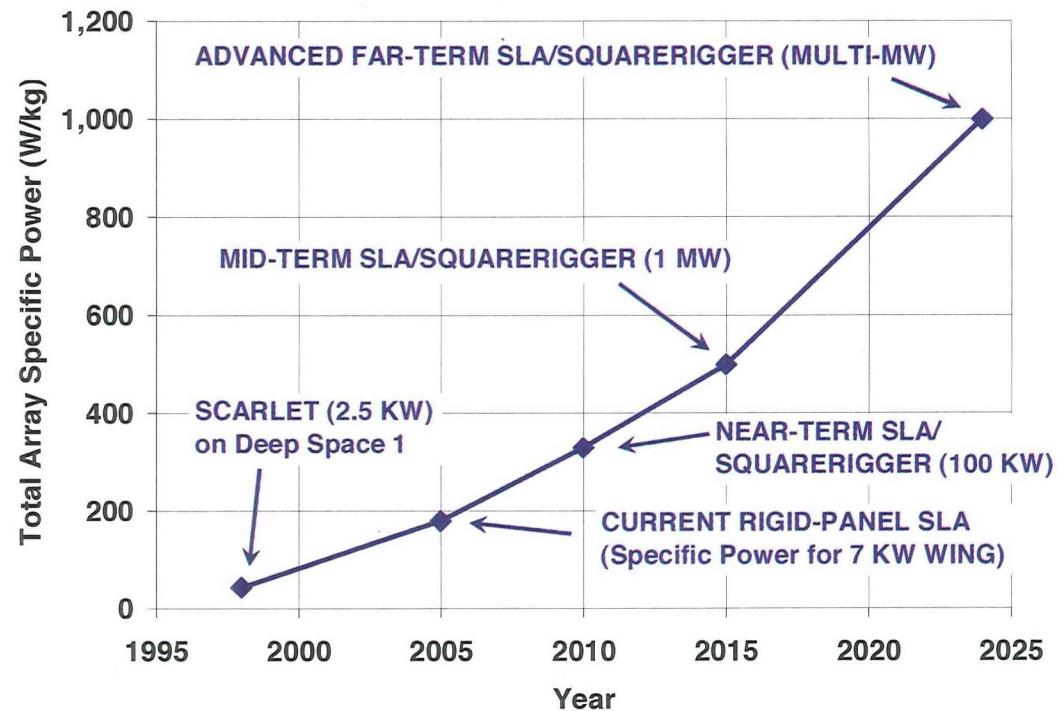
**This mass breakdown is for a near-term 100 kW SLASR
with today's 30% efficient cells and today's lens and radiator thicknesses**

Key SLASR Performance Parameters.

Parameter	Value for SLASR	Measurement or Model
Lens Transmittance	92%	Measurement
Cell Efficiency @25C	30%	Measurement
Net Lens/Cell Efficiency @25C	27.6%	Measurement (NASA Lear Jet Confirmed)
Cell Temperature on GEO	71C	Model (Validated on SCARLET)
Cell Temperature Knockdown Factor	91%	Measurement (Cell Temperature Coefficients)
Input Irradiance to SLA Lens	1,366 W/sq.m.	Measurement (International Standard)
SLA SquareRigger Gross Areal Power Density	343 W/sq.m.	Model
Wiring/Mismatch/Packing Knockdown Factor	90%	Model
SLA SquareRigger Net Areal Power Density	309 W/sq.m.	Model
SLA SquareRigger Wing Mass Density	0.853 kg/sq.m.	Model (Based on Prototype)
SLA SquareRigger Net Specific Power	362 W/kg	Model
SLA SquareRigger Stowed Power Density	80 kW/cu.m.	Model (Based on Prototype)

Stretched Lens Array SquareRigger (SLASR) Offers Spectacular Performance Metrics

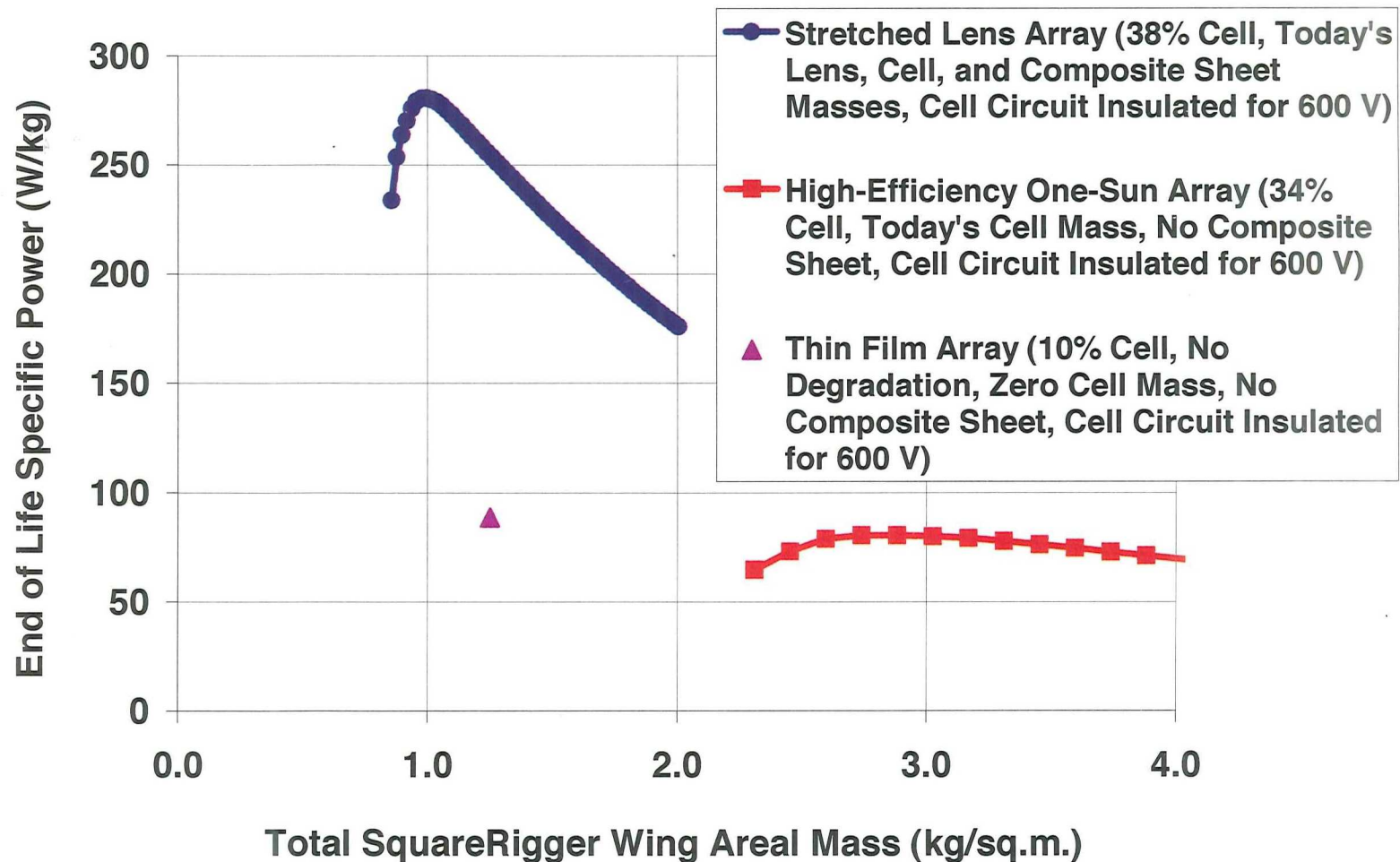
Time Frame	< 5 Years	5-10 Years
Power Capability (kW)	100	1,000
BOL Specific Power (W/kg)	330	500
Stowed Power (kW/m ³)	80	120
Voltage	1,000	TBD



SLASR Optimization for a Solar Electric Propulsion (SEP) Space Tug Mission with 7 Annual Trips from Low Earth Orbit to Low Lunar Orbit

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**Assumption: Total SquareRigger Array Mass = Blanket Mass/0.70
(Reference: ABLE's 100 kW SLA SquareRigger Design Study)**

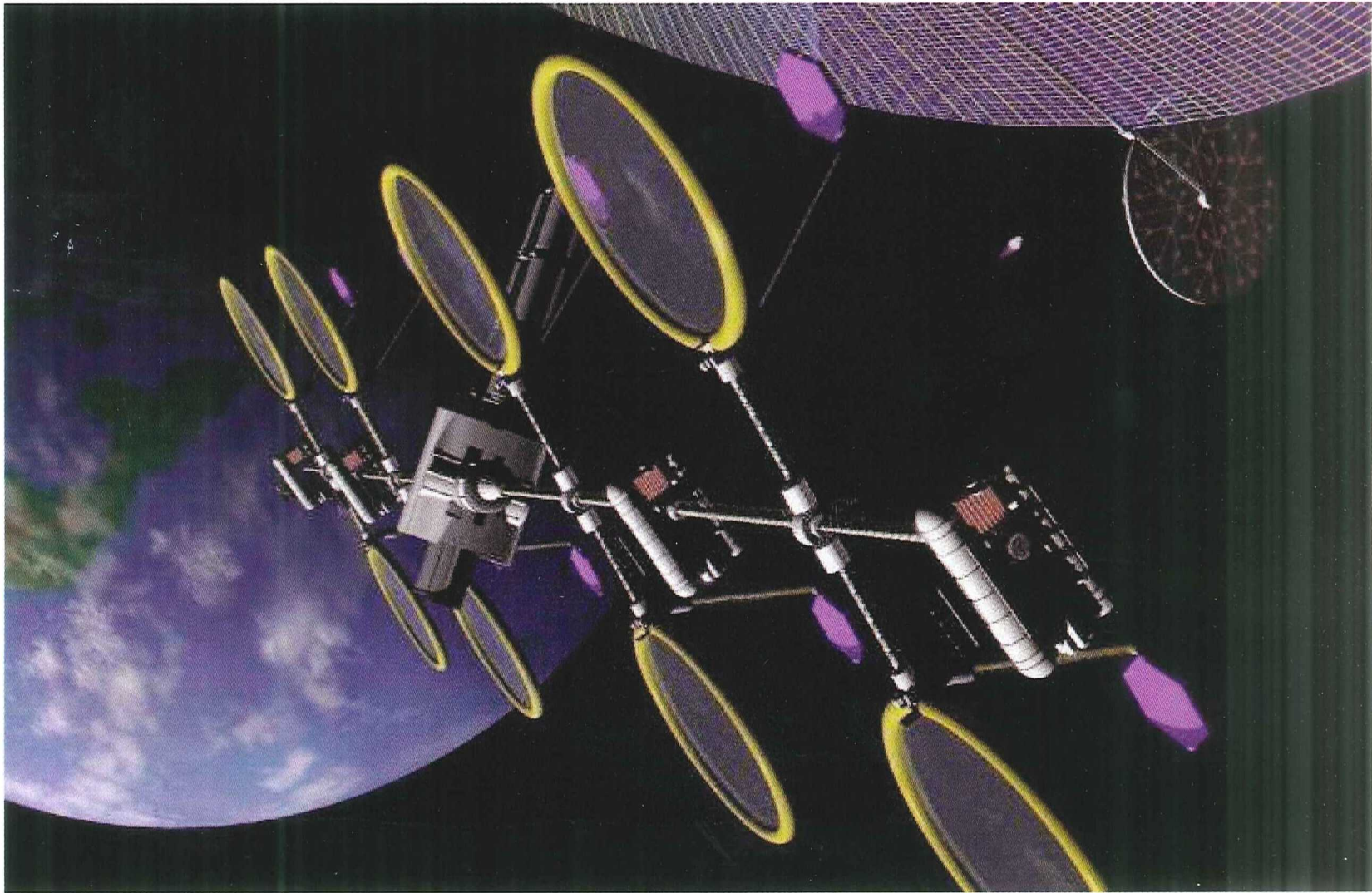


SLASR Advantages for Solar Electric Propulsion Missions

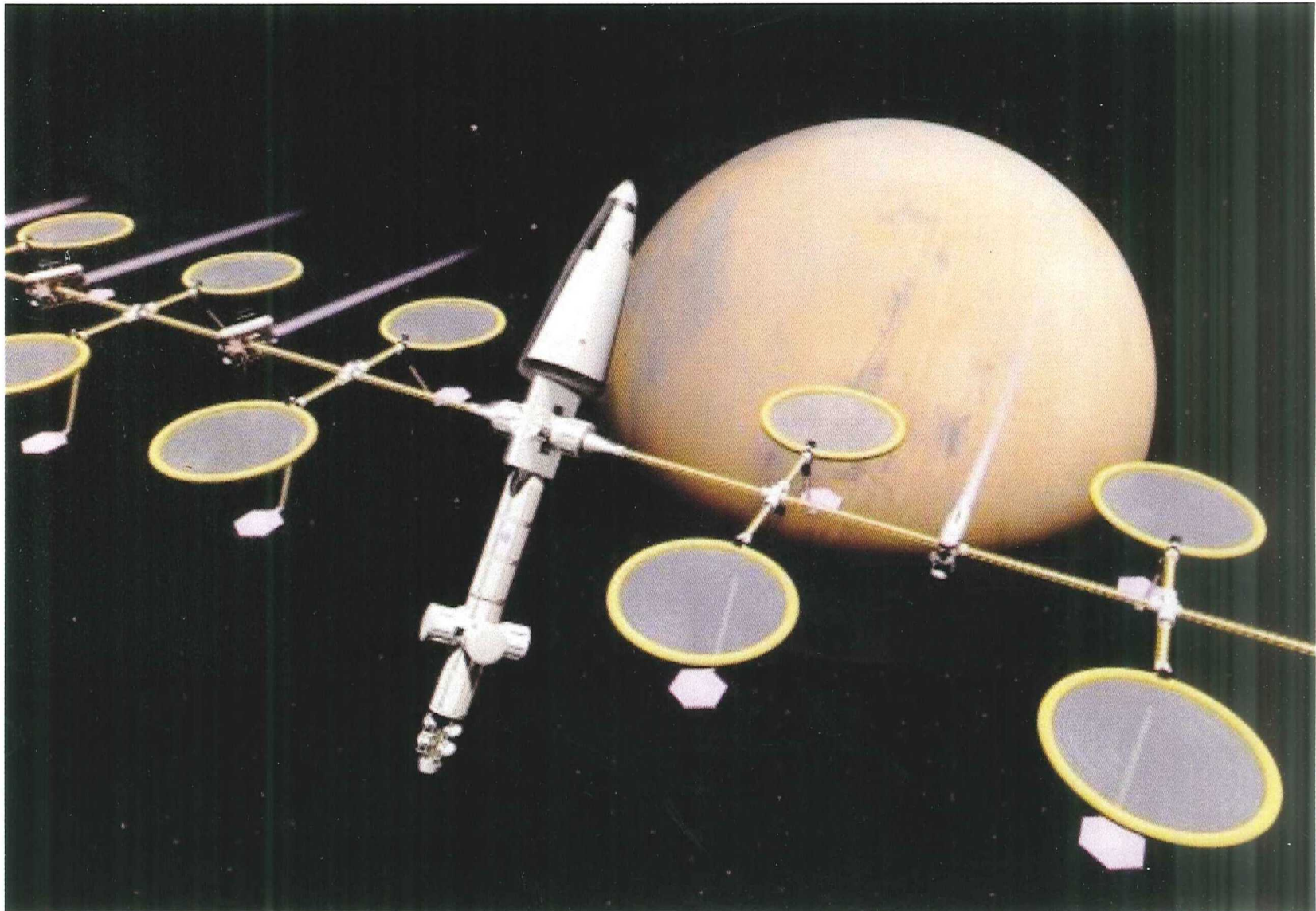
SLASR's Advantages for SEP Missions Include a Set of Unprecedented Performance Metrics and Features:

- Areal Power Density = 300-400 W/m²
- Specific Power = 300-500 W/kg for Full 100 kW Solar Array
- Stowed Power = 80-120 kW/m³ for 100 kW Solar Array
- Scalable Array Capacity = 100's of W's to 100's of kW's
- Super-Insulated Small Cell Circuit = High-Voltage Operation
- Super-Shielded Small Cell Circuit = Radiation Hardness
- 85% Cell Area Savings = 75% Lower Array Cost per Watt
- Modular, Scalable, & Mass-Produced at MW's per Year Using Existing Processes and Capabilities

A notional Solar Electric Propulsion (SEP) System – an Earth-Moon System
“Solar Clipper” – in operation, transporting large space systems to GEO



Another notional Solar Electric Propulsion (SEP) System – an Earth-Mars “Solar Clipper” – transporting large exploration mission systems and cargo to Mars orbit.



Conclusions

- Solar electric propulsion using direct-drive, high-voltage, high-performance solar arrays offers substantial benefits for delivering cargo in support of exploration missions to the Moon, and later to Mars.
- A single 600 kW reusable space tug could save over **\$3 billion** in launch costs alone in delivering 110 metric tons of cargo to the Moon.
- The critical enabling technology for such SEP space tug missions is the high-performance, ultra-light, radiation-durable, scalable, cost-effective, high-voltage solar array.
- The Stretched Lens Array (SLA) offers the portfolio of attributes and performance metrics needed for SEP space tug missions.
- Ground tests and later flight tests are critical to validate the SLASR technology for direct-drive SEP missions.
- Initial ground tests are underway and additional ground tests are planned for the next 2-3 years to support the development of SLA for direct-drive SEP missions.